A GEOSTATISTICAL ANALYSIS OF TEMPERATURES IN DEEP REGIONAL AQUIFERS, NORTHEAST BRITISH COLUMBIA

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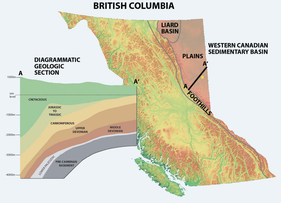
INTRODUCTION



Variation in the geothermal gradient as measured vertically within stacked aquifer zones of a basin indicates changes in hydrostatic flow and recharge between aquifer zones. This study identified three regional aquifers from Devonian to Cretaceous in age in northeastern British Columbia.
Using a database of temperatures collected from the open hole logging of oil and gas wells, over 100,000 observed geothermal gradient values were calculated and positioned three-dimensionally within the basin. Based on the stratigraphy from these same wells the geothermal gradient values were then partitioned into aquifer groups.
As expected, absolute reservoir temperature for each of the aquifer zones studied increased with burial depth. However, variations identified as "hot" or "cold" (above or below expected geothermal gradient) were observed within each of the aquifer zones. A local measure of spatial autocorrelation was used to analyse these "hot" and "cold" spots. The statistical test was performed at two scales identifying localized variations as well as broader trends within the aquifer zones. Descriptive statistics of each aquifer zone are also presented which provide additional information for consideration in interpretation. These variations in the geothermal gradient have implications for hydrocarbon migration/aquifer flow, and in regionally identifying aquifer temperatures conducive to geothermal energy development.

DATA

Temperatures:

- regulator maintains database of wells drilled in B.C.
- information on geophysical logs run stored in database
- over 100,000 records for logs
- information includes:
  - type of log run
  - date
  - unique well id
  - base of logged interval
  - temperature at base of logged interval

Locations:

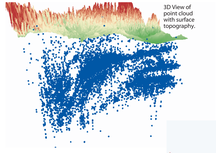
- surface location of wells are known
- elevations at surface determined using Digital Elevation Model (DEM)

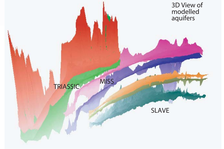
Gradients:

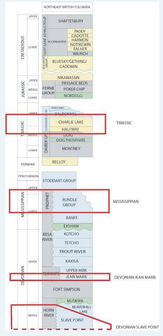
Geothermal gradient values were calculated for each entry in the database assuming an ambient surface temperature of 15 degrees Celsius.

$$T = Ts + GD$$

T = temperature at depth
Ts = ambient temperature at surface
G = geothermal gradient
D = depth from surface
(after Bachu, 2002)



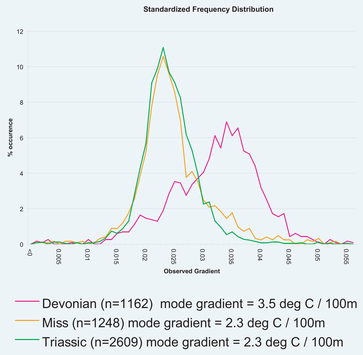




Aquifer systems

The Western Canadian Sedimentary Basin (WCSB) can be broadly divided into several stacked aquifer/aquitard systems.
Continuous and distinct aquifer zones include the lower Cretaceous Bull Head Group, middle to upper Triassic Schooler Creek Group (Halfway, Charlie Lake and Baldonnel formations); lower Mississippian Rundle Group; upper Devonian platform carbonates of Jean Marie, Kakisa, Tetcho/Kotcho formations; and the middle Devonian carbonate platforms of Slave Point/Sulphur/Keg River formations.
Of these the upper Triassic Schooler Creek Group, the lower Mississippian Rundle Group and the middle Devonian carbonate platforms are the most extensive and have thousands of temperature measurements that allow an analysis of geothermal gradients.
Temperature / Gradient readings were allocated to these aquifer systems based on their relationship to identified geologic tops in the database.
Basin wide hydrodynamic flow is driven by recharge in the foothills and Rocky Mountains in the west with fluids flowing up dip to the northeast (Bachu, 1997)

GEOTHERMAL GRADIENTS



Heat is created within the mantle or crust through the decay of radioactive isotopes. Within a sedimentary basin this heat is transferred to the surface through conduction and convection of fluids.

Current geothermal gradients are controlled by the combination of conduction and convection and can vary as a result of the relative importance of each.

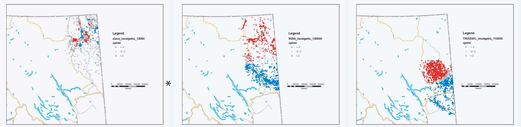
Hydrodynamic flow is generally driven by recharge in the foothills and Rocky Mountains to the west, transport down into the basin and flow up-dip to the east. Local variation spatially within each aquifer zone is potentially a result of variations of convection due to hydrodynamic flow.

GEOSTATISTICAL ANALYSIS

- used to quantify patterns in data.
- considers the quantity being measured (in this case geothermal gradient) and the distribution of points spatially.
- used Getis-Ord Gi* statistic.
- Gi* identifies groups of points with values higher or lower in magnitude than would be expected if the distribution was random.
- neighbourhood size can be used to investigate spatial patterns of different scale.
- produces Z score for each point.
- at confidence interval of 0.05:
  - points with Z > 1.96 are 'hot spots'
  - points with Z < 1.96 are 'cold spots'

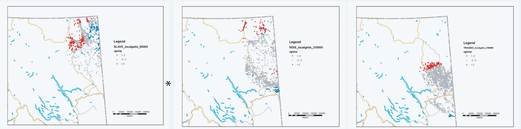
$$G_i^* = \frac{\sum_j w_{ij} x_j}{\sum_j x_j}$$

Small neighbourhood



Z-scores calculated using a small lag distance showing points with significantly high and low values. A strong north / south trend is apparent in the Triassic and Mississippian aquifers.

Large neighbourhood



Using a larger lag size the same trend is apparent. This lag size is approaching 1/2 the length of the study area.

*Slave Point (Devonian) was found to be corrupted by horizontal drilling. Many temperature readings associated with this aquifer system were in actuality readings from horizontal wells in shallower formations.

RESULTS

- data exhibit strong positive spatial autocorrelation within each aquifer unit.
- areas of lower than average geothermal gradient in Triassic and Mississippian aquifers are located in the foothills area.
- marked increase in the relative geothermal gradient of the Devonian aquifer system when compared to the overlying Mississippian and Triassic aquifer systems.
- elevated observed gradient values in shallower sections of the aquifers, corresponding to direction of fluid flow.
- Triassic aquifer on the whole is likely too cold to provide geothermal energy source (< 84 deg C).
- Mississippian aquifer appears to be of suitable temperature in vicinity of Fort St. John (~100 deg C).

DISCUSSION

- large scale trends in geothermal gradient apparent within Triassic and Mississippian aquifers.
- lower gradients in foothills could be interpreted as a result of influx and recharge in these areas.
- higher gradient regime in Devonian system could be interpreted as the result of high conductive heat flow from much deeper in the basin.
- elevated gradient values within each aquifer possibly due to convection within aquifer systems
- combining this data with regional porosity / water flow rates and observed bottom hole temperatures could highlight areas with potential for low temperature geothermal developments.

References:
Bachu, S. (1997): Flow of formation waters, aquifer characteristics, and their relation to hydrocarbon accumulations in the northern part of the Alberta basin; American Association of Petroleum Geologists Bulletin, v. 81, p. 712-733.
Bachu, S. (2002): Sequestration of CO2 in geological media in response to climate change: road map for site selection using the transform of the geological space into the CO2 phase space; Energy Conversion and Management, 43: 87-102.